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LCA of contaminated site remediation – integration of site-specific impact assessment of local toxic impacts

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1. Introduction

Life cycle assessments aim to compare environmental burdens associated with different ways of obtaining the same function or service denoted *the functional unit*. In the case of contaminated site remediation, most studies define the functional unit as the volume of contaminated soil or groundwater to be treated and combine it with a remedial target for the contaminant concentration [1]. However, although two remediation methods reach the same remedial target with time, their timeframes can be substantially different. This quality difference can be included in the LCA by assessing the so-called *primary impacts*. Primary impacts are local toxic impacts related to the contamination at the site as opposed to the *secondary impacts* stemming from the remedial actions.

Primary impacts have typically been assessed using *site-generic* characterization models representing a continental scale and excluding the groundwater compartment. Soil contaminants have therefore generally been assigned as emissions to surface soil or surface water compartments. However, such site-generic assessments poorly reflect the fate of frequent soil contaminants such as chloroethenes as they exclude the groundwater compartment and assume that the main part escapes to the atmosphere [2].

In this study we developed a methodology for inclusion of secondary secondary as well as primary environmental impacts associated with different remediation strategies for contaminated sites. Primary impacts cover the human toxic impacts due to contamination of groundwater used for drinking water. The multimedia fate and exposure model USEtox was used to evaluate toxic emissions for primary and secondary impacts. As the groundwater compartment is not included in USEtox we used an adapted version of the model to assess the exposure and potential impacts to the human population.

2. Materials and methods

The life cycle assessment of secondary and primary environmental impacts was conducted for two case localities, which both represents clay till sites contaminated with trichloroethene (TCE). Both sites are located within the groundwater catchment of a water supply well field.

For Site 1, the following remediation techniques were compared: 1a) In situ enhanced bioremediation, 1b) In situ thermal remediation and 1c) Excavation and ex situ treatment. The assessment for Site 2 compared two *in situ* options for remediating the site: 2a) In situ enhanced bioremediation and 2b) In situ chemical oxidation.

As mentioned above, site-generic characterization factors for toxic emissions do not adequately represent the fate of chlorinated ethenes at contaminated sites because they disregard deeper soil layers and groundwater causing the main part of the contamination to end up in the atmosphere [2]. Furthermore, they do not include the formation of metabolites during biodegradation of chlorinated ethenes, of which particularly vinyl chloride is problematic due to its toxic and carcinogenic effects [2]. The assessment of toxic impacts with the USEtox model was therefore combined with a site-specific assessment of primary impacts. This was done by the use of numerical models that took into account site specific fate and transport of trichloroethene including formation of metabolites according to the anaerobic sequential degradation pathway presented in Figure 1. The site-specific models estimated the contaminant mass discharge to groundwater over time in the baseline scenario (no remediation) and a number of remediation scenarios. These results were used to predict remedial timeframes to reach a predefined remedial target. Furthermore

they provided important inputs as design parameters of the different remediation systems compared and constituted the basis for estimating the local toxic emission to groundwater including formation of the degradation products (vinyl chloride and dichloroethene).

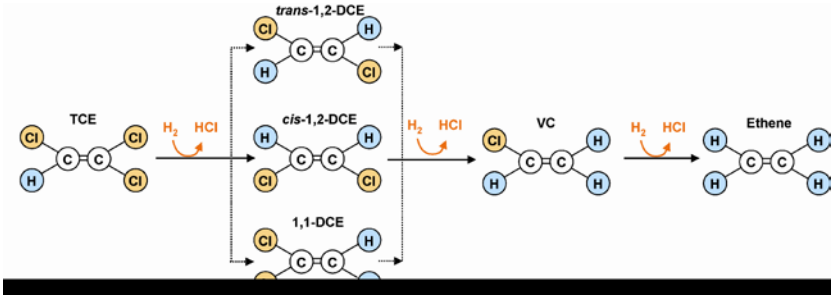

Figure 1: Enhanced bioremediation of trichloroethene (TCE) involves stimulation of the anaerobic reductive dechlorination pathway shown here. TCE is sequentially dechlorinated to ethene via dichloroethene (DCE) and vinyl chloride (VC).

In addition, site-dependent exposure parameters were used for calculation of exposure concentrations and the exposed number of people. Primary ecotoxic impacts in groundwater were neglected and no discharge to surface water is included because the groundwater plume is assumed to be fully abstracted by the downstream drinking water well.

3. Results and discussion

The results for Site 1 showed that enhanced bioremediation by enhanced reductive dechlorination was an environmentally preferred option compared to in situ thermal remediation and excavation with ex situ soil treatment. However due to the long timeframe of the bioremediation option, there are significant local toxic emissions to groundwater especially due to vinyl chloride formation. These local toxic impacts were, however, lower than the regional and global toxic impacts generated in the other remediation scenarios due to upstream production processes of e.g. steel components. The LCA gave insight into the contribution to environmental impacts of the different subparts of each remediation system and can be used to suggest environmental improvements of each system. The analysis of Site 2 is still undergoing, but the preliminary results indicate that in situ chemical oxidation using potassium permanganate generates higher environmental impacts than the enhanced bioremediation of the trichloroethene-contaminated site.

4. Conclusions

The local scale primary impacts were integrated in the traditional LCA framework by use of Usetox and advanced reative transport modelling. The methodology was tested at two case studies. The LCA results underlined that primary toxic impacts caused by release of chlorinated ethenes on-site during in situ bioremediation are important and should not be disregarded in the assessment. The assessment of primary toxic impacts due to leaching of chlorinated ethenes was based on detailed numerical modeling of fate and transport including metabolite formation and site-specific exposure parameters. The results showed that especially vinyl chloride, which is an intermediate product during anaerobic sequential degradation of trichloroethene, contributes significantly to the human toxicity of the bioremediation scenario (86-98 % of the human toxicity impacts at Site 1). As USEtox does not include metabolite formation and uses generic fate and exposure data, the resulting primary toxic impacts using this site-specific procedure are higher than if e.g. USEtox characterization factors for freshwater emissions were applied directly. The inclusion of primary impacts in the environmental assessment of remediation alternatives gave a more complete basis for comparison of technologies with substantially different timeframes and efficiencies.

5. References

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